

**Performance Analysis of Draught
Animal-Implement System to Improve
Productivity and Welfare**

Emmanuel Y.H. Bobabee

Faculty of Natural Resources and Agricultural Sciences
Department of Biometry and Engineering
Uppsala

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Cover photo: Sanga oxen pair harnessed with BBB yoke at
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Abstract

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Draught animal technology is a reliable and popular farm power resource in most developing countries. However, despite its growing popularity, animal traction farmers face several constraints such as rapid ploughshare wear, high draught forces and poor design of harnesses and other implements. Also, farmers and researchers have placed little emphasis on the importance of draught animal welfare issues.

The main objective of the thesis was to study the performance of draught animal-implement system to improve productivity and welfare. The specific objectives were to: (i) develop and test cast steel ploughshares for abrasive wear rate and perform comparative analysis; (ii) investigate optimum cutting edge thicknesses in relation to draught force and heart rates of work animals; (iii) analyse the effects of yoke design and loading transport implements on the productivity, comfort and welfare of oxen and camels; (iv) investigate the maximum loads that a camel can pull with carts and sledges without compromising its welfare.

The methodologies adopted were laboratory investigations into ploughshare chemical composition, hardness and production methods, cast steel share development, and field-testing of shares, yokes and transport implements.

The following conclusions were drawn from the study: (i) The newly developed cast steel shares were equally durable as the imported versions, and more durable than the local blacksmith forged shares (ii) The 2-4 mm share thicknesses emerged as the optimum share cutting edges that developed the least resistant forces and minimum stresses (lowest heart rates) when pulled by the animals. (iii) The yoke designs, which have increased contact areas in the animal's neck regions were more comfortable than the traditional yokes that have small contact points on the animals. (iv) At nearly constant walking speeds, the maximum loads camels pulled with cart and sledge were 5620 N and 2490 N, which were 119-143% of their body weights and equivalent to 53-64% pull/live weight ratios. The average pull/live weight ratios for the three camels ranged from 29-51% and 15-30% for cart and sledge, respectively, making the camels to perform nearly twice transport work in pulling loaded carts compared with pulling loaded sledges. The concept of performance index is introduced to evaluate draught animal power performance.

Keywords: draught animal technology, ploughshare, wear, cutting edge, draught force, heart rate, oxen, camel, yoke, animal welfare.

Author's address: Emmanuel Y. H. Bobobee, Department of Biometry and Engineering, Swedish University of Agricultural Sciences, P. O. Box 7032, S 750 07, Uppsala, Sweden. Email: Emmanuel.Bobobee@bt.slu.se

“The only thing I know I know is that, I don’t know anything”
Socrates

and

“If I have seen further, it is by standing on the shoulders of giants”
Isaac Newton

and

“In the middle of difficulties, lies opportunity” *Albert Einstein.*

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*To the memory of
my mother, Wotormedzior Afiba Dablu, and
grandmother, Wotameter Afiba Fenuku*

Appendix

Papers I-IV

The present thesis is based on the following papers, which will be referred to by their Roman numerals. Published papers are reproduced by kind permission of the journals concerned.

- I. Emmanuel Y.H. Bobabee, Kofi Sraku-Lartey, Simon C. Fialor, Emmanuel A. Canacoo, Sampson K. Agodzo, Albert Yawson, Girma Gebresenbet (2007). Wear rate of animal-drawn ploughshares in selected Ghanaian soils. *Soil & Tillage Research* 93, 299–308.
- II. Emmanuel Y.H. Bobabee and Girma Gebresenbet (2007). Effect of cutting edge thickness and state of wear of ploughshare on draught force and heart rates of Sanga oxen in Ghana, *Soil & Tillage Research* 95, 298-307.
- III. Emmanuel Y. H. Bobabee and Girma Gebresenbet. The Impact of Yoke Design on Physiological and Behavioural Responses of Draught Animals: The Case of Sanga oxen in Ghana. Presented at 5th International Colloquium on Working Equines (ICOWE 2006), Nov. 2006. Addis Ababa. Ethiopia, and submitted to *Biosystems Engineering*.
- IV. Girma Gebresenbet; Emmanuel Y. H. Bobabee; Pascal Kaumbutho; P S. Simpkin. Work performance, physiological and behavioural responses of camels when pulling carts and sledges. (*Manuscript*).

Notes on authorship of papers.

Paper I was planned by Bobabee. The experiments were performed by Bobabee with discussion inputs from the other authors. Bobabee also performed the data analysis and the writing with revisions from Gebresenbet.

Paper II was planned by Bobabee and Gebresenbet. Bobabee performed the experiments, data analysis and writing with revisions from Gebresenbet.

Paper III was planned by Bobabee and Gebresenbet. Bobabee performed the experiments, data analysis and writing with revisions from Gebresenbet.

Paper IV was initiated and the field experiment was planned and performed by Gebresenbet and Kaumbutho. Bobabee performed the data analysis and writing with inputs from Gebresenbet.

Relationship among the papers

This thesis focused on the efficient use of draught animal power by resource-limited farmers in developing countries. Paper I deals with developing a durable fast wearing replacement part (ploughshare) of the animal-drawn mouldboard plough. Investigations were conducted into the chemistry, production methods and performance of existing ploughshares leading to the development and field-testing of the new cast steel shares, which were found to be durable and could be mass produced.

Paper II extended the results of Paper I and dealt with welfare and comfort issues. In this paper, the cutting edge thickness and its location on the leading edge of the shares were analysed in relation to their impact on penetration and effects on comfort and welfare of animals.

Paper III evaluated the effects of yokes and yoke designs to estimate physiological performance and endurance of draught animals in relation to comfort and welfare. In Papers II, III and IV, welfare issues as they affect draught animals have been highlighted. Draught animal behaviour responses were investigated in Papers III and IV.

Paper IV is a pilot study and is regarded as an introduction to the research area of draught power of camels in sedentary agriculture in semi-arid areas. Both Papers III and IV dealt with welfare issues of transport animals.

Introduction

Global food supply is currently enough to meet the food needs of the world's population, yet hunger persists (Islam, 1995; Johnson et al., 1999). Over 850 million people around the world are undernourished with, nearly three quarters of them living in rural farming communities in South Asia and sub-Saharan Africa (Smith et al., 2000). Future increase in global population is projected to occur mostly in developing countries, where soil, water, and farm power resources are already under great stress (Fischer & Heilig, 1997 and Cohen, 2003). Food security for 850 million population is achievable partly through improvements in farm power availability to the resource poor farmers (Rosegrant & Cline, 2003).

Since the poor farmer's only asset is his own muscle power, increased and less variable rural labour productivity is an important intermediate objective in the struggle to end hunger and famine. Threats from scarce food supply will reduce if agricultural production technologies in use ensure ample local food supply. Scientists, especially those in developing countries can effectively address these issues through development and improvement of soil-specific and farmer-friendly technologies for predominant global agroecoregions.

From pre-historic times when man changed status from hunter-gatherer to settled agriculturist, he harnessed the muscle power of large domestic animals to augment his own physical efforts in food production and leisure. Nowadays in any agricultural crop production system, humans, draught animals and engines or motors provide the motive power in various proportions for crop production, harvesting, transport and processing (Rijk, 1989; FAO, 2003; Pearson, 2005).

Many studies have shown that farmers with access to their own farm power and machinery achieve better timeliness and intensity of farming operations (Sutton, 1989). According to FAO (2001), in sub-Saharan Africa, human power use accounts for 75 to 85 percent of harvested area. However, this dominance of human power is threatened by aging farming population, rural-urban exodus of the youth, increased school enrolment, and recently, the HIV/AIDS pandemic. These factors affect the work force and compel many countries to change their sources of farm power to overcome serious labour shortages. Pearson (2005) estimated draught animals and humans provide 80% of the power input on farms in developing countries, but lamented welfare and comfort of work animals are often neglected, because they belong to members of the poorest sections of society. High levels of tractorization are generally associated with relatively well-developed economies, the production of cash crops, profitable agriculture, operator skills, appropriate equipment and timely and cost effective repair and maintenance services (Rijk, 1989). Due to rising global fuel cost and the past failures of tractor mechanization projects in many developing countries, there is renewed interest in research and extension activities on efficient use of animal traction especially, for ploughing and carting.

Draught animal power (DAP)

Large domestic animals (cattle, buffaloes, horses, donkeys, camels, etc) when properly trained, fed and harnessed, are renewable source of energy. Wilson (2003) suggested that more than half of the world's population depends on animal power as its main energy source. The global population estimate of working animals is 300-400 million (Barwell & Ayre, 1982). This is an enormous resource equivalent to 35 GW of agricultural tractor power in those countries where they are used (O'Neil & Kemp, 1989), saving 20 billion tonnes of petroleum valued at that time at \$6-10 billion (Ramaswamy, 1998; Wilson, 2003), providing energy for cultivating 52% of the area sown and hauling 25 million animal drawn carts (Ramaswamy, 1998). Other estimates showed that in 1994 in developing world, 51% of the 921 million cattle, 35% of the 135 million buffalo, 65% of 43 million horses, 87% of 43 million donkeys, 70% of 14 million mules and 15% of 20 million camels were used for work (Pearson, 1999).

In sub-Saharan Africa, draught animals predominantly oxen, donkeys, camels and horses, are used on rain-fed lands in the cereal-based farming systems of western, eastern and southern Africa and the highlands mixed systems of Ethiopia. The use of animals for work in many parts of Asia, Northern Africa and Ethiopia, is part of a culture, where as in other sub-Saharan African countries, DAP introduction and adoption is recent. In Ghana DAP contributes 25% to cotton

production, and nationally its share of farm power has increased from 1-6% (Starkey, 1988; Bobobee, 1999). Although there will continue to be contributions from tractor power to land preparation, much of the region will continue to be cultivated using hand and animal power (FAO, 2003). However, any expansion of draught animal numbers will entail increased competition for fodder and pressures on arable lands (O'Neill & Kemp, 1989).

Inns (1997), categorised DAP into five distinct components, namely; animal, harness, implement, operator and the soil or load, whose condition or position we want to change. In the present thesis, the block diagram in Figure 1 is proposed to study the performance of the draught animal-implement systems. With respect to the above components and other factors including training, management, operational parameters such as speed and depth of ploughing as inputs, and productivity and animal welfare as outputs were considered. Whilst the farmer expects high productivity from his well-trained animal, it is important the welfare of the animal is not neglected. Despite the growing popularity of DAP, farmers still face several constraints. Some of the constraints are inefficient and unsuitable implements, rapid ploughshare wear, poor harness systems and bad yokes, high draught forces, poor management and animal welfare issues. In the present work, input parameters such as implement, (share quality), harness, operational parameters, soils and animals and their effects on productivity and welfare were studied

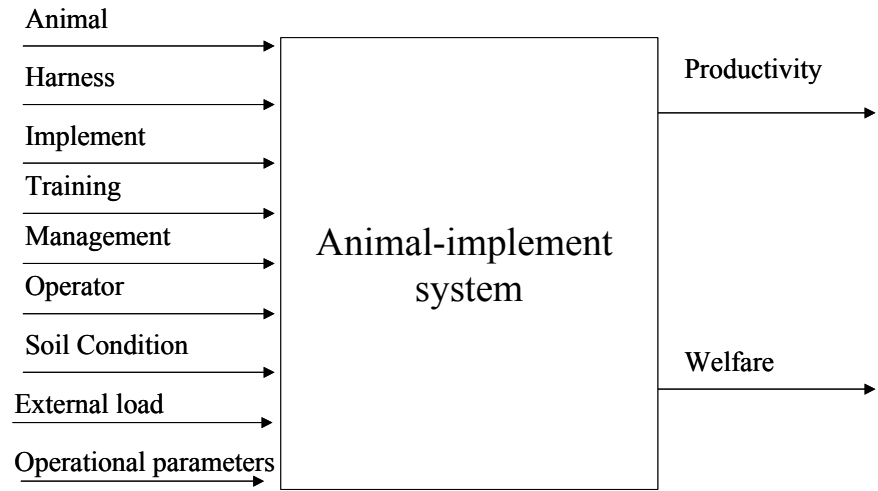


Fig. 1. Block diagram of the animal-implement system concept

This thesis focuses on developing durable ploughshares and promotion of draught animal welfare programs that can increase food production and security among resource-poor farmers. The durable locally produced ploughshare will accelerate the rate of gain in food production capacity and crop yields at local and national levels due to reduction in timeliness costs and savings in crop production.

Abrasive ploughshare wear

Wear is defined as damage to a solid surface, generally involving progressive loss of material, due to relative motion between that surface and a contacting substance or surface. Wear occurs when material is lost or displaced from surfaces that are in relative motion, causing a component to become ineffective or susceptible to sudden failure. Wear is described by a multitude of terms, examples of which are abrasive, adhesive, erosive and cohesive wear of polymers (Zum Gabr, 1979; Hutchings, 1992). Abrasive wear of ploughshares is the deterioration caused by hard soil particles because the share material is softer than the natural abrasives in the soil (Richardson, 1968; Natsis, Papadakis & Pitsilis, 1990). In Figure 2, wear due to abrasive soils have surface damage characterised by scoring, cutting, deep grooving and gouging, and micromachining, caused by soil constituents moving at a relative velocity of about 1 ms^{-1} on a metal surface (Ferguson, Fielke & Riley, 1998). For a given tillage tool, the amount of wear decreases when the hardness exceeds that of the soil abrasives. Figure 3 displays actual samples of the new and worn cast steel shares developed during the study. The share is declared worn by the farmers when they realised further use will damage the frog, the central part to which all other components are attached.

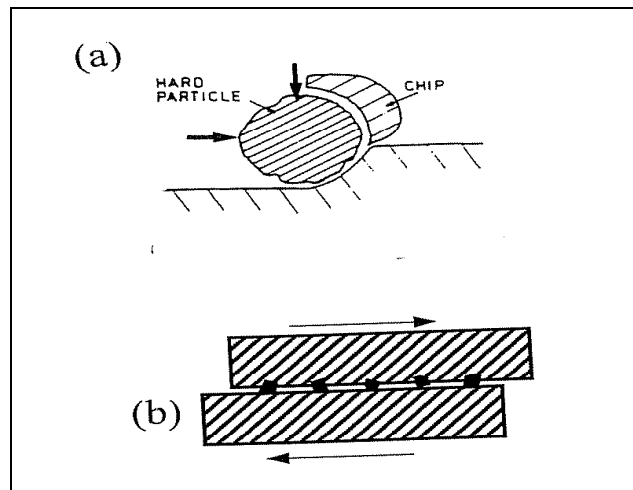


Fig. 2. (a) Abrasive wear depicted as the damage produced by a hard particle moving under normal and tangential forces; (b) two-body abrasion, in which hard abrasive particles are attached to one sliding surface. (Source: Hutchings, 1992)

Soil texture and share wear rate

Soils with stones and gravel accelerate wear. Abrasive wear rate in stony soils was detected by Scheffler & Allen (1988), to be twenty times higher than in sandy soils and seven times greater than in the clay soils. Quirke, Scheffler & Allen (1988), showed the durability of ploughshares varied from 4 ha for soils containing rocks and gravel, to about 100 ha for loam soils containing 10-25% clay. Owsiak (1997), also found the wear of cultivator points to be 40-100%

higher in sandy loam soil than in light clay soil, because the sandy soil is associated with larger diameter soil abrasives with increasing unit pressure and microcutting ability. Wear in compacted soil was reported to be 31% greater than that in loose soil (Owsiak, 1997). Singh, Shukla & Singh (1993), attributed the wear of reversible shovels to be dependent on the material of manufacture and the soil type.

Most researchers agree wear rates increase as soil moisture content decreases (Natsis, Papadakis & Pitsilis, 1999). Under dry conditions such as 2% mc (db), Ferguson, Fielke & Riley, (1998), observed shares wore at a rate of 4.25 times faster than in wet conditions (18% mc db) with an average life of 9 km compared with 38.4 km, respectively. However, Yu & Bhole (1990) and Baryeh (2001) have shown contrasting results of an increase in wear rate in sandy soils with increase in water content. According to Miller (1984), the effect of moisture content on the wear rate of tillage tools is dependent on soil type, being different for sandy soils than with clay soils.



Fig. 3. Display of new and worn shares of cast steel samples developed during the study.

Economics of ploughshare wear

Wear of ploughshares leads to frequent work stoppages for replacement and contributes to high costs in parts, downtime and labour estimated to be several millions dollars annually (Quirke, Scheffler & Allen, 1988; Yu & Bhole, 1990; Ferguson, Fielke & Riley, 1998). According to Williams (1997), replacement costs of worn implements by animal traction farmers in parts of Niger led to the

abandonment of the technology. The average area worked by a 'good' share before replacement in Zimbabwe is about 2 ha (Agritex, 1986). In Ghana, depending on soil conditions and ploughman's experience, Dibbits & Bobabee (1996), reported the average wear rates of the local blacksmith and 'good' imported shares were 1-2 ha and 2-5 ha per share, respectively.

Generally, abrasive wear of soil-engaging tools is influenced by several factors. These include chemical composition of the steel and its heat treatment, operational factors and characteristics of the tools. The rest are the soil type and conditions, the distance travelled or area worked, and for multi-tine arrangements, the position of the wearing part of the tool. Most research studies to determine wear and durability of ploughshares have focused on tractor-drawn implements, and mainly in the developed countries. Few studies have been reported on the wear of soil cutting tools driven by animal power, and where the chemical composition and production methods of these tools are different.

Ploughshare sharpness and draught force

To maintain soil quality, reduce cost and environmental effects, Arvidsson, Keller & Gustafsson (2004), recommended ploughing should be carried out under favourable soil conditions with as little energy input as possible. According to McKyes (1985), draught forces are more complex to describe mathematically. Arvidsson, Keller & Gustafsson (2004), calculated draught force from measurement of fuel and speed, and concluded draught was related to depth of ploughing, with the greatest draught obtained at the share (Gebresenbet, 1989; Shoji, 2004). Most of the literature on cutting edge thickness in relation to draught force and energy consumption relates to use of tractors for such measurements (Natsis, Papadakis & Pitsilis, 1999). Literature is scarce on optimum share cutting edge, durability, wear related field efficiency, research related to physiological response of animals, and variation of force. Further research seems justified to specify the ideal cutting edge of tillage implements and the effect on tillage performance in different soils.

One area that warrants attention regarding efficient use of DAP is the interaction between draught force and tillage implement cutting edge sharpness to give longer life and promote draught animal welfare. Foundries and blacksmiths produce tillage implements from thicker materials. The thicker materials result in blunter cutting edges. Research has shown that forces on tillage implements are altered by wear, which changes the geometry of the cutting edge, depending on the soil type and conditions (Fielke et al., 1993). A blunt cutting edge is reported to increase the draught force and the upward acting vertical force, which tries to lift the implement out of the soil (Inns, 1990). Natsis, Papadakis & Pitsilis (1999), measured draught of six different cutting edge thicknesses (1-6 mm) of shares and found the draught force to increase with cutting edge thickness with exponential fitting. Fielke (1996) in his research to specify the ideal cutting edge on a tillage implement and its effect on the tillage performance reported an increase of 80% in draught force for ridger shares cutting edge thickness from 1–10 mm. In order to

observe the interactions that occur between animals and implements that may influence performance, O'Neill & Kemp (1989) treated the animal-implement system as a single entity and illustrated with nominally steady state values, the wide ranges of effort and power associated with draught animal cultivation.

Many studies were carried out to establish the relationship between body weight and pulling capacity of draught animals. Horses, donkeys and camels are reported to pull about 10% and 25-34% of their body weights (Goe, 1989). Singerland (1989), used donkeys between 100-140 kg and reported the maximum pulled force to be 480 N, with an average force measured for 8 h continuous work to be 450 N and 5-10 min/h rest periods. Load levels and live weight ratios are linked to animal productivity and welfare.

Performance of draught animals in some countries

Table 1 illustrates the performance variations of different draught animals in undertaking various tasks. Average draught forces developed during ploughing, ridging, weeding and carting vary between 300 and 1000 N. From the table, camel, horse and cattle are better suited for heavy primary cultivation than donkeys, which must be in a team of at least four to provide a reasonable draught force. Draught forces encountered in secondary cultivation (weeding), and carting are lower than those recorded for primary cultivation. Draught forces are higher for cattle and horse than donkeys in pulling loaded sledges. For operations requiring low draught like secondary cultivation and transportation, the equines and the camel are more efficient than the bovine. The donkey, horse and camel are also more efficient regarding their pull/live weight ratios than the cattle. With regards to speed, camels, donkeys and horses are generally faster than oxen. In reality, work output is not just a function of the animal itself, but could be influenced by the type of implement, depth of working, training levels of the animals, operator skills, soil and animal conditions and time of day, as postulated in the '*performance index*' (PI) concept in this thesis. Adverse working conditions such as heat stress, badly fitting harness and difficult soil conditions will also reduce rate of work and performance of animals (Pearson and Vall, 1998).

Table 1. *Performance of some draught animals in different countries.*

Source	Country	Animal	Implement	Harness	No in team	Average live weight (kg)	Duration of work (h/day)	Speed (m/s)	Average draught force [ADF] (N)	ADF (% of live weight)	Average Power (W)
Hagmann and Prasad, 1994	Zimbabwe	Cattle	Plough	Yoke	4	367	3.6	1	800	6	800
Ndlovu et al., 1996	Zimbabwe	Cattle	Plough	Yoke	2	270	3	0.88	442	9	428
Fall et al., 1997	Niger	Cattle	Plough	Yoke	2	400	-	0.92	978	13	900
Bartholomew et al., 1995	Mali	Cattle	Weeder	Yoke	2	300	3.5	0.77	613	11	470
Bartholomew et al., 1995	Mali	Cattle	Ridger	Yoke	2	300	4.5	0.74	778	13	591
Nengomasha, 1997	Zimbabwe	Cattle	Plough	Yoke	2	280	-	0.63	832	15	527
Dave and Mukherjee, 2001	India	Cattle	Plough	Yoke	2	228	-	1.1	547	12	602
Rodriguez et al., 1999	Columbia	Cattle	Plough	Yoke	2	528	-	0.84	976	18.5	820
Vall, 1996	Cameroon	Cattle	Loaded sledge	Yoke	2	400	5.5	0.74	1000	12.5	740
Hagmann and Prasad, 1994	Zimbabwe	Donkey	Plough	Collar	4	120	2.6	0.86	730	15	586
Nengomasha, 1997	Zimbabwe	Donkey	Plough	Collar	4	164	-	0.62	823	13	510
Vall, 1996	Cameroon	Donkey	Loaded sledge	Collar	2	125	4.3	0.8	350	14	280
Gebresenbet and Kaumbutho, 1997	Kenya	Donkey	Plough	collar	1	186	9	0.8	465	25	372
Singerland, 1989	Mali	Donkey	Plough	Collar	2	120	8	0.8	450	37.5	360
Aguirre and Orihuela, 2000	Mexico	Horse	Plough	Collar	2	205	5.5	0.8	935	23	748
Vall, 1996	Cameroon	Horse	Loaded sledge	Breastband	2	263	5.3	0.92	736	14	677
Wilson, 1978	Sudan	Camel	Plough	Saddle	1	475	-	1.0	736	16	750

Harnessing and comfort

The pulling power of draught animals (DAs) is transmitted to implements by means of harnesses in the form of collars, breast bands or yokes. Various types of harnesses are in use throughout the world, although they vary greatly in design and detail. The most effective type of harness depends on the species and breed of animal. Bovines (cattle and buffaloes), which constitute more than 75 percent of working animals, are better suited for yoke harnesses because of their strong shoulders (Matthews, 1986). Head yokes are not suitable for humped (Zebu) cattle (*bos indicus*), which in general have weak necks, compared to non-humped (*bos taurus*) types. The double withers yoke is usually simple in shape and construction, and is easy to make by the rural farmer. However, it has the tendency to cause shoulder sores and other discomfort to the animals if not shaped or padded properly (Barwell & Ayre, 1982). To gain maximum benefit from the animal, Pearson (1986) made the point that health, better feeding, training and improved harnessing should be given equal treatment.

Most research in draught animal technology focused on improving implements, nutrition and health of animals. Research into comfortable yokes for bovines has not attracted equal attention. Since DAs are sentient beings, a good and comfortable harness will reduce pain, improve welfare and increase the overall productivity of draught animals and farmers (Ramaswamy, 1998). Webster (2001) defined welfare of a sentient animal according to its capacity to sustain fitness and avoid pain and suffering. Pain and distress are core issues in the field of animal experimentation and in the controversy that surrounds it.

Draught animal welfare

To ensure that DAs carry out timely work, they require care and proper husbandry to prevent stress and reduced health (Pearson, 1986). According to Fraser (2001), farmer attitudes toward animals have undergone a gradual evolution driven by the recognition that humans and many other species share a lot in common. Ramaswamy (1998) advocated draught animal welfare programmes have to focus on prevention of cruelty and pain, and foster care and well being because many subsistence farmers who use DAs are not sensitive to animal suffering and invariably overload and overstress their animals. The emerging awareness about animal suffering and welfare has been accompanied by an increasing public agitation especially in developed countries for avoidance of cruelty to animals in pursuit to satisfy utilitarian ends (Fraser, 2001; Lund, 2006). Many countries have enacted legislations and guidelines that outline the need to minimize pain and distress to animals and the recognition of consumers willingness to pay for animal welfare products (Burgess & Hutchinson, 2005; Boogaard, Oosting & Bock, 2006; Maria, 2006). In the European Union, animals were granted the status of 'sentient beings' through the Treaty of Amsterdam in 1977 (European Union, 1977). As a result of all these, there is a demand for more knowledge regarding animal welfare – for example, what affects it, how to measure it, and how to implement it (Lund et al., 2006). To resolve this situation will require research to create an accurate understanding of the diverse effects of modern animal agriculture, together with

measures to harmonize agricultural practices with changing public values (Ramaswamy, 1998).

Welfare indicators

Most farmers in their motivation to harness the animal power for work usually force their DAs to exert far more effort than required, especially at the onset of the rains during land preparation. This compromises the welfare of their animals after the long dry periods when the animals do not have the best condition (Batholomew, Khibe & Little, 1994). It is generally assumed that welfare is intimately connected with the physiological stress response, with less stress indicating good welfare (Duncan, 2004; Webster, 2001).

Dawkins (2006) emphasized it is difficult to measure welfare and feelings. However, it is possible to get some indication of what an animal is feeling by indirect means through its physiological (e.g., cortisol levels and heart rate) and behavioural responses, (e.g., vocalization, defecation and working speed). It is also well known that physical activity and stress increase heart rate, blood pressure and cortisol concentration (Richards & Lawrence, 1984; Renecker & Hudson, 1985; Purwanto et al., 1990). According to Eckert, Randall & Augustine, (1988); and Jones et al. (1989), during exercise, heart rate is one of the three parameters that contribute to the oxygen uptake.

Heart rate and welfare

Monitoring heart rate (HR) relies on the simple observation that the harder the exercise activity, the faster the heartbeat. Heart rate is a major variable frequently used to evaluate athletic horses exercising on the track or treadmill (Holopherne et al., 1999). According to O'Neill & Kemp (1989), heart rate generally regarded as a reliable indication of workload, correlates reasonably well with stepping rate, speed and power. Recent work by Betker, Susenbeth & Buchenau (1996), and Buchenau (1999), which concentrated on the determination of the energy expenditure of donkeys, turned out to be closely correlated to the animal's heart rate. Brosh et al. (1998), used HR to estimate energy expenditure of farm animals including cattle mostly under controlled and confined conditions and applied quadratic regression equations to best describe exercising animals. Therefore HR, a relatively easy measurement, which reflects a degree of strain, could be used to accurately estimate energy expenditure and animal welfare.

Current advances in biomedical technology provide the opportunity for more sophisticated studies on animals and their stress responses. With few exceptions, the act of studying an animal affects what is being studied and can confound interpretation of the results. Therefore, there is a strong need to minimize study-induced disturbances. This can be achieved by both reducing the extent of contact and the invasiveness of hands-on studies and, where practicable, engaging in hands-off studies. Heart rate and levels of stress hormones such as corticosteroids have been used as physiological measures of welfare (Broom, 2001; Korte, 2001; Gregory, 2004). In principle at least, these measures are useful in species such as

cattle that are considered stoic and unlikely to show pronounced behavioural responses to pain until injuries are advanced (Weary et al., 2006). There is a long history of using physiological responses in assessing pain and distress. Unfortunately, the inclusion of physiology and behaviour studies in assessing draught animal welfare is not yet widespread. Millman et al. (2004), described animal welfare science as “a young science”.

Rai & Khanna (1990) made an important investigation on physiological responses of camels to load variations, using camels of three breeds. The authors reported that the variation of load from 1200 to 1800 kg caused an increase of 67-267% in respiration, 41-70% increase in pulse rate and 2.1-3.45 °C rise in rectal temperature. The increased pulse and respiration rates when using two wheel carts were 69% and 125%, where as for four wheeled carts the increased figures were 38% and 71%. This means the stress level could be reduced by about 45% when using four-wheel cart. Maloiy, Rugangazi & Rowe (2004), in their studies in Kenya, found heart rate (HR) has close relationship ($R^2 = 0.92$) with energy expenditure either at rest and exercise in the one-humped camel and concluded HR could be a useful indicator of energy expenditure in camel. Stride length, stride frequency, heart rate and energy expenditure all increased with increased speeds in camel (Maloiy, Rugangazi & Rowe, 2004).

Behaviour and welfare

Harnessing animals for work with poorly designed and badly fitting yokes, inappropriate and incorrect use of equipment is painful to the animals and constitutes an important welfare problem (O’Neil & Kemp, 1989; Wilson, 2003). This is accompanied by increases in heart rate and resistance to move, and behaviour alterations such as vocalization (Watts & Stookey, 1999) and propensity to defecate. Vocalization expresses a distinctive inner state of an animal that may occur spontaneously or may be the result of an external event (Grandin, 1998). Hence, it seems to be reasonable to regard vocalizations as easy indicators of an animal’s state of welfare (Dawkins, 1998). It must be mentioned that interpretation of vocalizations and defecation is not completely sufficient regarding the evaluation of well being in animals (Koene, 1996; Chedad et al., 2001; Tokuda et al., 2002). Some chronically bad physical conditions may be expressed by non-vocalization sounds, as for example cough, or decreased rates of vocalizations that are neutral to welfare, e.g., sequences of progeny or territory calls. Traditionally, cattle show little or no faeces avoidance behaviour (Hafez & Schein, 1962, and Kilgour & Albright, 1971). These behavioural adaptations can be described as protective, allowing animals to avoid or reduce the stimulation of painful tissues (Mellor, Cook & Stafford, 2000). Higher frequency, intensity and duration of vocalizations, defecation, lying or refusal to walk, have been reported as pain signals in animals (Taylor & Weary, 2000; Taylor et al., 2001). Negative welfare and pain lead to activation of the hypothalamus-pituitary-adrenal (HPA) and sympathetic axes, which cause higher plasma adrenocorticotrophic hormone (ACTH) and cortisol levels (Hay et al., 2003). Less information is available on the physiological effects, particularly the acute phase response, during several stages of work of draught oxen and camels.

The use of behavioural parameters in assessing the welfare of open-housed dairy cattle in Ghana, and working equines in urban and peri-urban areas in Afghanistan, Egypt, India, Jordan and Pakistan was stressed by several researchers (Kabuga et al., 1992; Pritchard et al., 2005).

Considering the growing interest in animal welfare issues and the huge amounts of conventional energy draught animals save globally (Barwell & Ayre, 1982; Ramaswamy, 1998; Wilson, 2003), reliable research results in the area are needed for legislation and welfare codes to be soundly based on scientific knowledge. To date, literature is scarce on attempts to validate such welfare measures specifically in relation to comfort, pain and behavioural responses of draught animals, and none to our knowledge has compared the effects of share wear rate and sharpness, and yoke designs that transmit muscle power and draught animal welfare.

Further research seems justified to specify wear rate and the ideal cutting edge spectrum of tillage implements in different soils and the effects on animal welfare. Also, with increasing use of camels for draught, the need to evaluate not only their pulling capability, but also the implications of the pulled implements on the comfort and welfare of the animal has become more apparent.

Objectives

The main objective of the thesis was to study the performance of draught animal-implement system to improve productivity and welfare as illustrated in Figure 1. Specific objectives were to:

- (i) develop a cast steel ploughshare and compare its wear rate and durability with existing animal drawn ploughshares in Ghana by investigating the relationship between wear rate and major contributing factors (Paper I).
- (ii) determine the optimum cutting edge thickness of new animal-drawn mouldboard ploughshares that gives the least draught force and lowest heart rates when pulled by animals (Paper II).
- (iii) study the effects of different yoke designs on the physiological and behavioural responses and welfare of oxen when pulling various loads on farm tracks (Paper III).
- (iv) determine the maximum load camels could pull using cart and sledge without inducing harmful stress (Paper IV).

Materials and methods

This study seeks through laboratory and field experimental procedures to add to the empirical base of the literature on the productivity, comfort and welfare of draught animals. The laboratory experiments included investigation of share chemical composition and determination of soil condition parameters. The field experiments were done on-station and on-farm. Detailed field experimental designs are given in corresponding papers.

Study sites

The main field studies were done in real farmer environments, and mostly in the drier areas of Ghana (papers I, II & III) and semi-arid parts of Kenya (paper IV). In Ghana, two on-farm sites in the north were located in the Guinea-Savannah agro-ecological zones at Tamale (9°28'N and 0°55'W), and Wa (10°05'N and 2°30'W), and the third was a coastal on-station near Tema (4°10'N and 0°02'W) in the south. The soils were a mixture of Eutric Plinthosols, Plinthic Lixisols, and Haplic Luvisol (FAO, 1998). Precipitation in the northern sites occurs between May and September with a unimodal peak. The Tema site has bi-modal precipitation peaks. Precipitation at all the three Ghanaian sites is unevenly distributed both in time and in space. The monthly rainfall and temperature distribution from 1990–2004 for the test sites are illustrated in Figure 4. The field experiments were carried out from May–June 2002 to May–December 2004. On-farm trials were established with 38 farmers selected randomly from villages in the predominant animal traction zones in the north. The farmers were considered major stakeholders of the research output and were involved in the studies from an early stage for their views to be taken into consideration. This was to ensure sustainability of the final project outcome

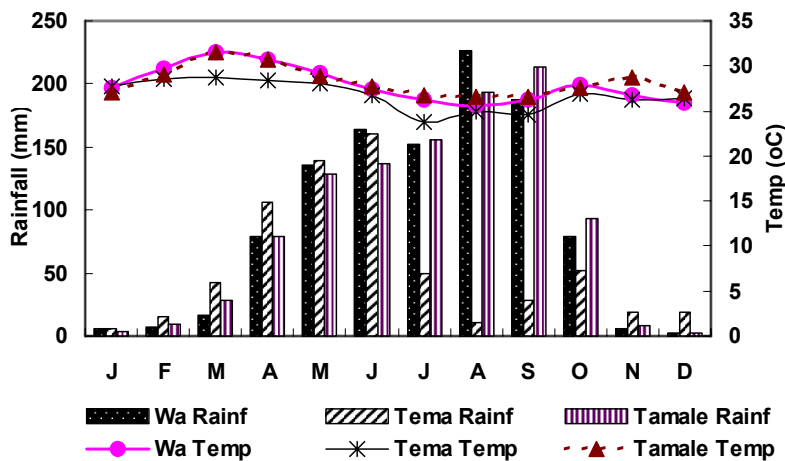


Fig. 4. Monthly rainfall (Rainf) and temperature (Temp) distribution for Wa, Tamale and Tema (1990 – 2004) test sites.

The on-station trials were carried out at the Nungua Agricultural Research Station (ARS) farms of the University of Ghana, because it has facilities such as well-trained draught animals and experimental plots for field research in animal traction studies and demonstration teaching.

The work in Paper IV was undertaken in the semi-arid zone of central Kenya near Nanyuki town (0° 01'N and 37°04'E). A four hundred meter long grass field, along with walkways was used. Possible obstacles were removed but the field surface was very irregular.

Ploughshare 'germplasm' collection and field testing (Paper I)

Used and new ploughshares, which included locally produced and imported samples were collected from farmers, blacksmiths and foundries and their microstructure and chemical composition analysed. The quantometer method was used to determine share chemical composition and hardness. A new chemical composition was formulated to produce cast steel shares because facilities for press forging were not available locally during the study. A recommended composition of 0.4-0.5% Carbon, 0.6-0.7% Manganese, 0.2-0.3% Nickel, 0.1-0.2% Chromium, 1.3-1.6% Silicon, 0.12% Sulphur and 0.05% Phosphorus was given to local foundries for production. These cast steel shares were heat-treated, air-cooled, tempered and their cutting edges were tested for hardness.

The durability and wear rates of the existing and new cast steel shares were assessed through on-farm trials. Farmers were given new shares to use during the major land preparation seasons with the understanding to give access to the research team to monitor and measure ploughed fields periodically. Share wear rate was derived from weight loss (g) and area ploughed in hectares. Under similar soil conditions and uniform travel speed, a tractor-mounted mouldboard plough was fitted with the low carbon shares (imported, cast steel and blacksmith) and used to plough part of the farmers' fields to determine wear and durability.

Ploughshares cutting edge thickness (Paper II)

Six different ploughshare cutting edges and four worn shares were fitted onto a plough bottom and used for the experiments. Three forms of share sharpening were detected at the top (Reversed), back (Regular or conventional) and both edges (double-sided). The four worn shares collected from farmers and tested were (i) three samples of cast steel shares labelled A, B & C, and (ii) one sample of the double-sided cutting edge, designated as 'arsws'. All the worn shares originally had 2 mm cutting edges. Shares manufactured by local blacksmith normally have cutting edge thickness of 8 mm. The worn shares were accepted as declared by the farmers, when it became evident the frog would be exposed to damage.

All the new shares were part of the improved cast steel shares developed, tested for wear and durability and reported in Paper I. The share sharpened at both edges was an imported pressed forged version. The performances of the new shares and

their cutting edges were compared in relation to depth of penetration, draught forces and heart rates of oxen. The worn shares were also evaluated with respect to draught force and heart rates. The average masses of the new and worn shares were 2.0 and 1.0 kg, respectively.

For the cutting edge thickness studies (Paper II), field-tests were done on plots which were previously ploughed and harrowed and left for some weeks to consolidate to reduce the influence of soil condition variations during measurements, following the method described by Gebresenbet & Kaumbutho (1997). A fixed ploughing depth was set and maintained throughout the field trials. It was assumed that if the plough depth, speed of operation and soil conditions were maintained as uniform as possible, the resulting operational depths of penetration, draught forces and heart rates of the animals could be associated with the cutting edges of the shares used. The field tests were randomised complete block designs (RCBD) and evaluated using analysis of variance (ANOVA).

Draught animals (Papers I, II, III & IV)

Oxen and camels were used during this study. The animal traction farmers in Ghana used a mix of local oxen breeds such as Ndama, West African shorthorn (WASH), Sangas and Zebus. Animal effects were not investigated with the farmers' experiments. However, during the research station trials on share cutting edge and yoke design experiments, only Sanga oxen were used. Dromedary camels were used in Kenya. The detailed descriptions of the animals are covered in the papers annexed.

Animal behaviour & welfare (Paper II, III & IV)

The behavioural changes as indicators of welfare of the animals were observed and noted during work. Behaviour observations started in the morning from the time of confinement for instrumentation to the period after work when the animals were grazing. Activities were classified as pain related during work, and trained observers executed the observations, which did not consider treatments related to yoke and harness types. Speed reduction as sign of tiredness or stress was measured.

Qualitative observation method was employed to analyse the daily behaviour of the animals during the tests. The common aggressive and amicable behaviour patterns monitored were: refusal to enter confinement prior to the instrumentation exercise, urinating, defecating, aggressive head and horn swaying and tail movements. Others were, head butting, vocalization, skin shaking, resistance to instrumentation and yoking or harnessing, refusal to move, salivating and lying. During work, behaviour alterations of the animals were observed when various loads were applied, and when people and other animals passed.

Harnesses (Paper III, & IV)

Withers yokes for oxen and high hitch saddles for camels were used for the experiments. The yokes tested for comparison were the traditional yoke with circular cross-section (SA), local version of a typical American yoke (BBB), and a modified traditional yoke used for training at the Research Station (ARS) (Paper III). The three yokes ARS, BBB and SA weighed 10, 20 and 9.8 kg, respectively.

A simple harness free from mite infestation and made out of three rolled-up sisal sacks were used (Paper IV). The saddles, which were used mainly for carrying loads or people, normally sit over the hump. However, the weight of the saddle rested on the ribs and not on the hump itself. Some of the saddles were adapted for pulling carts and ploughing. The harnesses used for the test were ensured to efficiently transmit pulling energy from the animals to the implements. Additionally, the harnesses and the saddles did not have sharp edges to injure and inflict wounds, impede the movements and natural breathing of the camels. In selecting the saddles to use, they were inspected for sufficient padding between the hard frames or the load and the camel body. Other good attributes of the saddles were the ability to sit firmly on the animal not to cause friction, and wide enough to distribute pulling and weight bearing forces over bigger areas. Sledges were used for both oxen and camels, and two-wheel carts were used only for camels.

Instrumentation

Heart rate and sensor (Papers II, III & IV)

The heart rates (HR) of the animals were measured to estimate the stress induced by each cutting edge, yoke design, loaded sledges and carts. HR was measured continuously 5-30 minutes before start of experiment, throughout the experiment, and 8-20 minutes after work (resting condition). Mounting of the sensor itself induces stress on the animal, and the above time was needed for the heart rate to come to resting condition after sensor attachment. The measurements were started after the heart rate attained the resting conditions. Heart rate data were collected simultaneously at a sampling rate of 5 s intervals. The POLAR® 610i Accurex instrumentation was used (Polar Electro, Oy, Finland). Data from the receiver were later transferred to a computer for further visualization and processing. The Polar HR meter provides a non-invasive and convenient means of assessing HR during exercise with improved accuracy. This device was used effectively on oxen and camels working in the field doing draught work (Figure 5). Heart rates above normal resting or recovery levels were indication of illness, injury, stress, and anxiety or overwork.



Fig. 5. Instrumented oxen pair during a typical pulling exercise

Dynamometer for draught force (paper II, III & IV)

Two kinds of dynamometers (RON 2000, and an extended octagonal ring dynamometer) were used. Tri-axial extended octagonal ring dynamometer was used for the measurement of forces during the camel experiments. It was mounted on the pulling line of the cart and the sledge (Paper IV). Full description of the design principles and performance characteristics of the dynamometer are detailed by Gebresenbet (1989).

A commercial electronic dynamometer RON 2000® (Eilon Engineering, Israel), with digital data logger was used to measure resultant draught forces with the oxen. At work, the dynamometers were free to align with the draught chain so as to detect the resultant pulling forces. Pulling force measurements were taken after the plough had settled in the soil at the operational depth, or when the animals have moved past a fixed starting point along the track. The horizontal component of the draught force was a function of the hitch angle and the measured force along the chain. A distance counter was used to measure distance travelled during pulling to derive average speed of operation from the time taken to travel specified distances along the plots and tracks during each trial.

Soil physical measurements

Soil penetration resistance, bulk density, moisture content and soil texture were measured during ploughing tests. In each field, six sampling points at corners and

midsections were identified for measuring soil strength in the 0–30 cm layer at 5 cm intervals. A hand operated recording type cone penetrometer with a 30° steel cone of 1 cm² base area (Eijelkamp Agrisearch Equipment, Giesbeek, The Netherlands) was used. Measurements were made in each plot on the same day for the cone index, bulk density and moisture content.

To analyse the bulk density and moisture content, six soil samples were taken at each farmer's field in the surface 0–25 cm at 5 cm depth increment using a core sampler (Eijelkamp, The Netherlands). The undisturbed soil cores were taken close to the penetration resistance points and dried in an oven for 24 h at 105°C, and then weighed to calculate bulk density (Blake and Hartge, 1986). Soil moisture content was determined gravimetrically from bulk density samples. Composite samples collected from 0–10 and 10–20 cm soil layers were used for soil particle-size distribution and texture (USDA textural triangle). Soils were air-dried and passed through a 2-mm sieve before analysis. Soil particle-size distribution was measured by the hydrometer method (Gee and Bauder, 1986).

Statistical analyses

All data were analysed using the SAS Statistical Software Package (1999). The PROC GLM procedures were used to perform analysis of variance (ANOVA), multivariate analysis of variance (MANOVA), cluster analysis (CA), principal component analysis (PCA) and correspondence analysis. The data were processed by PCA and only the principal components that explained more than 70% of the variance were selected, based on eigenvalue >1 rule. Principal component analysis (PCA) was used to summarize the measurements made on wear rate and chemical composition, wear rate and soil physical parameters and the camels heart rates at the three states (dynamic, steady and global) as a response over time.

The MANOVA approach was also used to test the hypothesis that the chemical compositions of the shares were the same from all producers. The differences in the shares based on producers were further verified by cluster analysis and confirmed during the tractor field-testing to compare the wear rates of the shares. Means were separated using the least significant difference (LSD) when treatment effects were significant. CANOCO (ter Braak, 1987) was used for the partial detrended canonical correspondence analysis (pDCCA) of wear rate and share chemical compositions (Paper I).

Single linkage measuring the Euclidean distance has been used (Papers I & IV). In this thesis, we are interested in hierarchical clustering techniques for wear rate and producers, heart rate classifications that are scalable with time and also suitable for implement comfort and welfare of draught animals.

In Paper II, the SAS PROC GLM procedures were used for the descriptive statistics and ANOVA of the depth of ploughing, draught forces and heart rates for the different cutting edges. Normality of the data was tested, and homogeneity of variances was examined by plotting residuals versus predicted values using GLM procedures. Draught forces of all 2 mm edge shares (i.e., 2 mm conventional,

double-sided and Reversed) were also compared. Additionally, draught forces of worn shares were compared with new 2 mm cutting edge share.

In Paper III, factorial analysis was used for heart rate data for each animal for all the three yokes and the five load levels with the following statistical model:

$$y_{ijk} = \mu + \alpha_i + \beta_j + (\alpha\beta)_{ij} + \varepsilon_{ijk}$$

Where, Y is the dependent variable (heart rate), μ the overall mean, α_i the load level effect (i =1,2...5), β_j the yoke effect (j=1,2,3), $(\alpha\beta)_{ij}$ is interaction term, and ε_{ijk} is the residual error, assumed normally and independently distributed (k=1,2...,6, number of replications). When a significant difference was found, means were separated using Duncan' multiple comparison test (Steel & Torrie, 1980). Differences were considered to be significant at $P \leq 0.05$. Additionally, cluster analysis methods were also used to form groups of heart hearts based on load and implement multivariate datasets. Observations that were similar appeared in the same cluster. Statistical significance levels were set at $P \leq 0.05$. Asterisks indicate significant differences between points at a given stage (** = $P \leq 0.01$; *** = $P \leq 0.001$).

Results and discussion of the papers

Share chemistry and production methods (Paper I)

The relation of the wear rate to share chemical composition, production method and producers, and the influence of major soil physical factors were analysed using multivariate statistical approach (Figures 6, 7 & 8). These analyses were made for field results obtained from farmers, who independently tested the shares on their farms with minimum interference. Results of comparative tests of cast steel, imported and blacksmith shares (low carbon shares) using tractor, grouped the farmers' fields according to sand contents only (Figure 9).

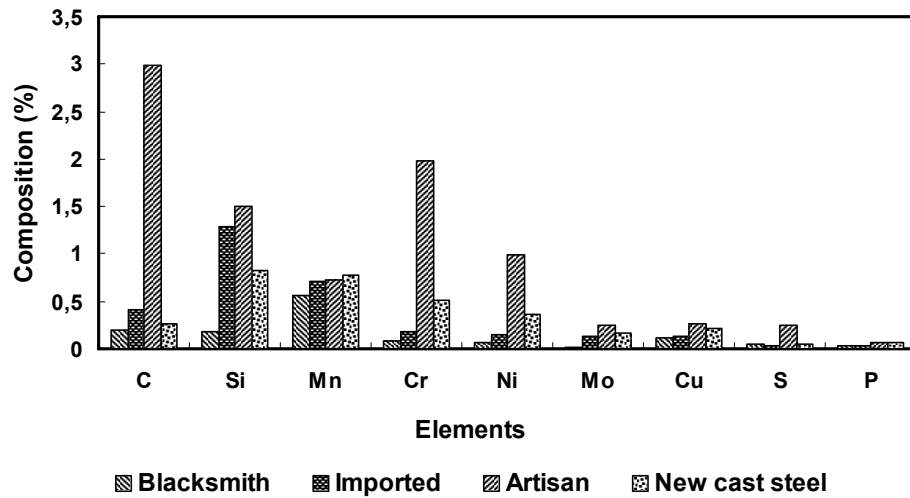


Fig. 6. Distribution of the major elements in the different ploughshares from the four producers

The distributions of the main elements in the ploughshares from different producers are shown in Figure 6. The analysis of the chemical composition of the shares showed that the highest concentration of C (2.985%) and Cr (1.986 %) were exhibited by the cast iron shares produced by local artisan casting. There were variations in alloy contents of the shares. These cast iron shares were very hard but too brittle and they fractured upon impact. The blacksmith, imported and cast steel shares were considered low carbon steel in comparison to the cast iron shares. The multivariate analysis of variance (MANOVA) method was used to compare the chemical composition of the shares and their producers. This revealed results, which were used to formulate new chemical composition to develop the cast steel shares that balanced hardness with toughness. A further MANOVA analysis of all the shares including the newly developed cast steel used the test criteria of Willks' Lambda and Pillai's Trace to confirm significant differences ($p \leq 0.05$) existed among elements of shares from different producers. This result was further confirmed through correlation among the different elements. Correlation coefficients of 0.411 and greater indicate a statistically significant ($p \leq 0.05$) relationship among the elements. High correlations exist among few elements, ranging from 0.411 (Si–Cr) to -0.663, between Cr and P. The correlations between elements Si–Cr (-0.411), C–Mn (0.421), Mo–Si (-0.425), S–Mn (0.480), S–Mo (0.481), C–Mo (0.506), S–C (0.603), and P–Cr (-0.663), support the assumption of common or similar origin of the scrap metal raw materials used by the blacksmiths and the foundries. An interesting result is that Ni and Cu have no correlation with any other element. Nickel gives strength and makes steel ductile and is an element that favours graphitisation, whereas copper is an austenite stabiliser and acts to delay the start of the transformation to pearlite. Copper can replace part of Ni when it is used to delay the start of the pearlite transformation. The high correlation between Cr and P (-0.663) might be explained by the fact that whereas chromium contributes to hardness and abrasion

resistance, phosphorus in small quantities helps in fluidising cast material. This ability helps carbide distribution in the material, thus increasing volume fraction of carbides in the share microstructure and improves wear resistance in agreement with the findings of Owsiak (1997).

Cast steel share chemical composition and wear rate

The relation between the chemical compositions and the wear rate of the new cast steel shares are shown in Figure 7. The pDCCA results used correlation to show relationship among the elements and the wear rate data from different farmers' fields. Some correlations exist among majority of the chemical elements and wear rate. Mo and S appeared close, which agrees with the findings in the correlation matrix ($r=0.481$) in Paper I. Sulphur increases machinability. Nickel, Silicon and Sulphur are more strongly correlated with wear than Cr, Mn and P. Nickel gives strength and makes the cast steel ductile, and it is the most positively correlated with wear rate. Nickel's role is to favour graphite formation, and it could also be well done by using Silicon. Carbon in this graph is used as proxy for hardness. Carbon in the form of carbide negatively influences wear.

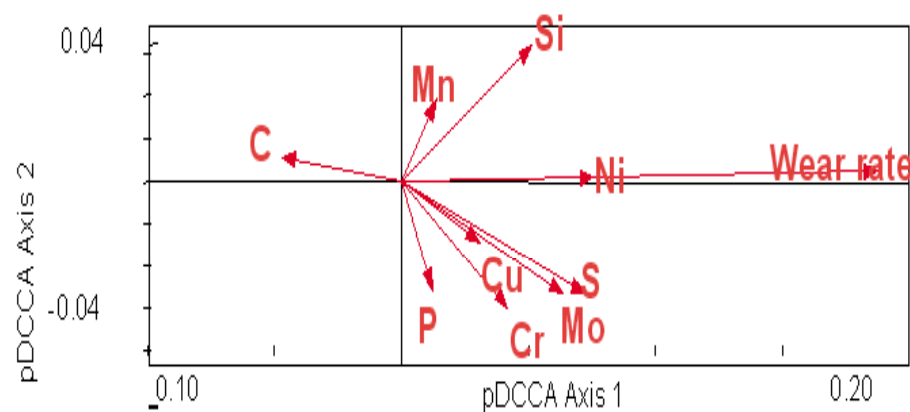


Fig. 7. Ordination diagram displaying the first two axes of partial Detrended Canonical Correspondence Analysis for the cast steel share chemical composition and wear rate.

Soil physical parameters and wear rate

PCA plot in Figure 8 summarised the effects of share hardness and soil physical conditions on share wear rate. Three components with eigenvalues > 1 that contributed 70% or more of the total variation, were considered. The first component explained 32% of the total variation and evaluated the contributions of sand and bulk density with the wear rate of shares. Share hardness and moisture content were the strong factors in the second component contributing 20% of the total variation. Cone index was the main factor influencing the third principal component, which explained 18% of the total variations. All the soil physical parameters showed some correlation with the wear rate, evidence that they influence rapid wear (Figure 8). The wear rate is more strongly correlated with the

sand and bulk density than with moisture content and cone index. This implies the higher sand fraction, bulk density, and cone index indicated compacted soils with increased abrasive abilities, affected share wear rate in this study.

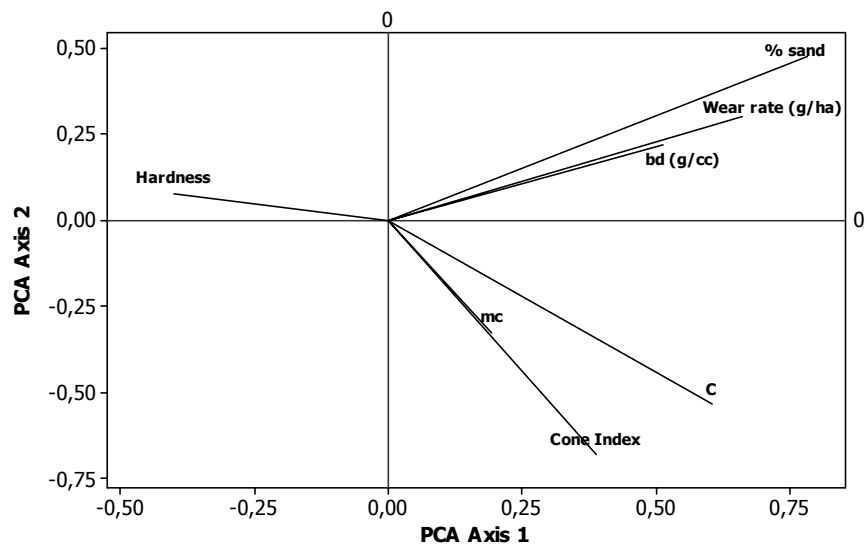


Fig. 8. The PCA loading plot summarising the effects of soil physical conditions and share wear rate.

The field soils have low contents of silt, clay and organic matter and were extremely hard during dry seasons. In conformity with increases in bulk density, the penetrometer resistance also increased. Normally, high cone index values are expected in compacted soils indicating increased unit pressure and hence increased abrasive forces (Owsiak, 1997). Wear rate is negatively correlated with share hardness. This is in agreement with the findings of Foley et al., (1984) and Owsiak (1997). This is expected and could be attributed to additional factors such as share work hardening due to surface temperature heating caused by friction leading to embedment of abrasives (Scheffler & Allen, 1988).

Sand ($p \leq 0.001$) and share hardness ($p \leq 0.018$) significantly influenced wear rate. This evidence supports the fact that sand promoted rapid abrasive wear of ploughshares in the study, in agreement with the findings of several studies (e.g., Richardson, 1968; Quirke, Scheffler & Allen, 1988; Ferguson, Fielke & Riley, 1998; Yu & Bhole, 1990; Owsiak, 1997; Baryeh, 2001). However, since the field data was gathered from several farms at different times, similar relationships between wear rate and moisture content that could not be controlled were inconsistent with the regression equation (1) in Paper I.

Share chemical composition, soil physical parameters and wear rate plots are helpful in explaining the existence of any latent gradients in the data. The field data rather than simulated data were used to extract 'natural' patterns, but one cannot be certain that the results are 'correctly' summarised by any one ordination.

However, given that we cannot know a priori what these ‘true’ patterns are in field conditions, we have deduced the effects of such choices by comparing the results from a number of analyses. The PCA and pDCCA allow the use of samples, variables and covariables (e.g. chemical composition, cone index, moisture content, bulk density, share hardness, and wear rate), which are not measured in the same units to be analysed to reveal any relationship among them. The above analyses were meant to determine the limited number of factors, which explain animal-drawn ploughshare wear rate in the arable soils of Ghana.

The soils at various test sites were sandy loam in the top 0-10cm layer and belong to three FAO (1998) classifications, namely; ‘*Eutric Plinthosols*’, ‘*Plinthic Lixisols*’, and ‘*Haplic Lixisols*’. The average wear rates in these soils were 146 g/ha for Eutric Plinthosols, 164 g/ha for Plinthic Lixisols and 176 g/ha in the Haplic Lixisols. The overall average wear rate of 162 g/ha was equivalent to share durability of 3-8 ha/share when most shares were not declared completely worn by farmers. Other factors also likely to affect wear rate could be operator skill and experience in implement adjustment and handling, training levels of animals and ploughing speed, which unfortunately were outside the scope of the present study, but were suggested in the ‘*performance index*’ concept.

On-station and on-farm trials with tractor to compare wear rates of imported, blacksmith and cast steel shares under similar field conditions and uniform travel speeds are shown in Figure 9. The wear rates of the imported and cast steel shares were closely related but lower than the blacksmith’s share in all sandy soils. At normal tractor ploughing speed, the average wear rates of all shares increased with increasing sand content of the soil.

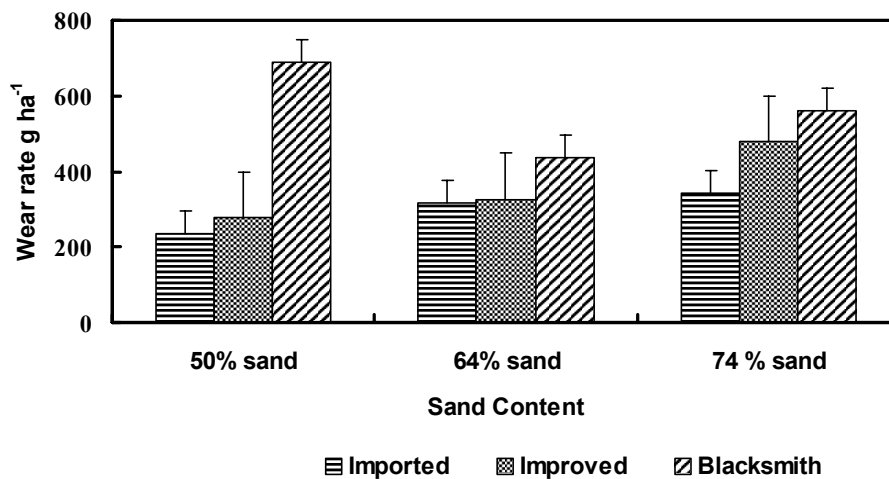


Fig. 9. Wear rate of three types of share in different sandy soils ploughing with tractor. The improved share is the same as the cast steel share.

The moderate wear rate of the new cast steel shares in comparison with the imported and blacksmith versions has positive implications for its mass production in the country. This means cost savings and increase in productivity for the farmer due to savings in timeliness cost to replace and change shares. This could contribute to lower cost of land preparation and food production. It is also likely to translate into national capacity building and savings for the farmers and the country since the new shares are cheaper and do not depend on foreign exchange. Presently, the imported share costs twice as much as the cast steel version and about four times more than the blacksmith share in the farming communities. During the study, no farmer reported a fractured cast steel share. This is a good result for a cast tillage implement that could withstand dynamic shocks during ploughing.

Share cutting edge and depth of penetration (Paper II)

The variations in the average penetration depths of the various share cutting edges and geometry are shown in Figure 10. These caused variable loads and stress on the animals. The 1 mm cutting edge and double-sided cutting edge shares penetrated deeper than the 2, 4, 8 mm and Reversed cutting edges. The 2 mm maintained a mean depth of penetration equal to the original depth of 15 cm set for all shares.

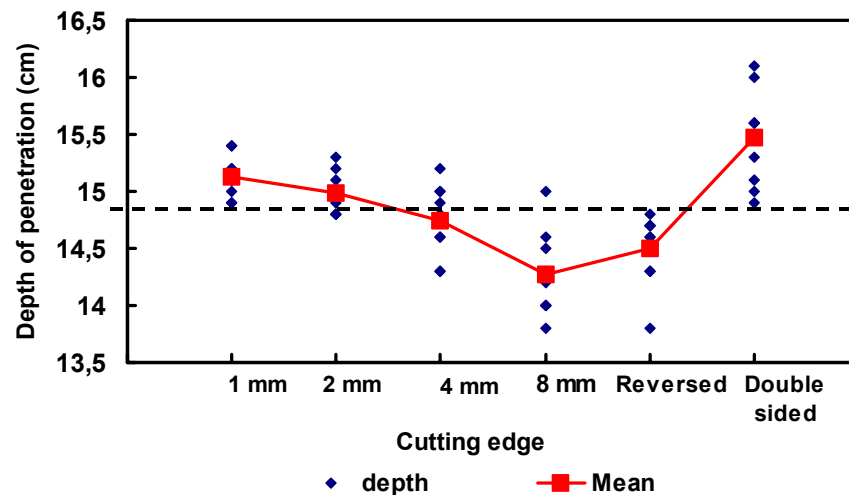


Fig. 10. Scatter plots of average penetration depths in relation to the set depth of 15 cm.

Since the cast steel shares have the same profile and curvature, the variations in depth of penetration could be attributed to the cutting edge thickness. In the case of the Reversed, its shallower penetration could be influenced by its cutting edge geometry, which was at the top leading edge. The new cast steel shares have thicker section of 11 cm compared with 8 cm for the pressed forged double-sided cutting edge. The section thickness and cutting edge geometry could also influence the deep penetration of the double-sided share in comparison with similar cutting

edges of the cast steel versions. The thinner imported share sliced the soil more easily. Even though the field was prepared prior to the experiment to minimize soil heterogeneity, variation of ploughing depth could result from many factors including field condition either weedy, moist or dry, and crumbled from earlier ploughing, surface roughness, soil physical parameters, sinkage of the depth wheel and working speed, which could not be controlled.

The penetration of the cutting edges varied from an increase of 7% to a decrease of 8% from the set depth. This is in agreement with the findings of Arvidsson, Keller & Gustafsson (2004), who reported a 6% increase and 11% decrease from set depths for a tractor-drawn mouldboard plough in moist soil.

Cutting edge and draught force profiles

In Figure 11 the resultant draught force profiles for the 8 and 2 mm cutting edges are compared, showing cutting edge thickness has a strong impact on the draught force variation. It gave an indication of the magnitude of draught force developed by the different cutting edges and the accompanying stresses they will induce on the animals. The profile analysis shows draught force fluctuates between peak and trough values as the implement was pulled in the soil. Peak values indicated share cutting unbroken or hard soil, and the trough values signalled ploughing failed or friable soils or when there was reduced tension in the pulling chain.

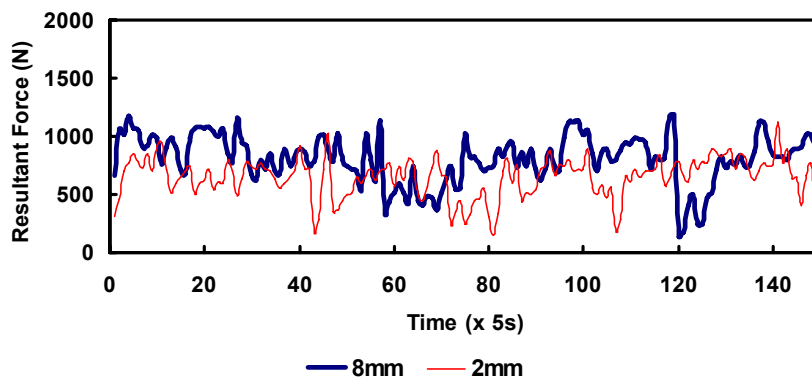


Fig. 11. Typical profiles of resultant draught force variations with time for the 2 and 8 mm cutting edge shares

Cutting edge influence on draught force and heart rates

In Figure 12, with the exception of the 1 mm edge, the mean resultant draught force (a) and heart rates (b) increased with increasing cutting edge thickness for the 2-8 mm, including the Reversed and double-sided edges, which were also of 2 mm sharpness. The lowest heart rates of the animals and minimum draught force values were consistent for the 2 mm cutting edge rather than for 1 mm, the sharpest cutting edge. The high values for the 1 mm edge could be due to its deeper penetration (*see* Figure 10).

The average draught force recorded by the Reversed was higher compared with that of the 2 mm, but lower than the double-sided. The Reversed had a shallow depth of penetration (*see* Figure 10) and its form of sharpening or cutting edge geometry could only explain its high draught values in comparison with the 2 mm. The front sharpening of the Reversed could potentially create a wedge and bulldozer effects on the soil leading to an increased normal force. The high draught force associated with the double-sided cutting edge could also be attributed to its deep penetration, a factor that might result from its mode of sharpening on both edges and could be responsible for the highest observed values among all cutting edges in the experiment. Additionally, the geometry rather than sharpness of the double-sided and the Reversed cutting edges might have influenced the draught forces and the corresponding heart rates of the animals. The high draught values exhibited by the Reversed and double-sided cutting edges indicate the animals will be over stressed by these methods of share sharpening. Lower draught forces are associated with generally lower heart rates as seen with the 2 mm and 4 mm cutting edges (Figure 12).

The ANOVA of these cutting edge draught forces were highly significant ($p \leq 0.001$). The lowest resultant draught forces of 647 and 656 N were recorded for the 2 and 4 mm cutting edges, respectively. By changing the cutting edge thickness from 2 mm to 8 mm, (sharp to blunt), the mean draught force increased by 29%. The resultant forces for 1 mm, Reversed and double-sided cutting edges were 706, 864 and 1067 N, respectively. Compared with the 2 mm cutting edge force, these values were 9%, 35% and 65% higher, respectively. This compares favourably with the findings of Natsis (1999), who observed a 62% increase in draught force for 1-6 mm increase in cutting edge thickness. The accompanying heart rate ANOVA also confirmed there were significant differences ($p \leq 0.05$) in the mean heart rates of the oxen pair in relation to share cutting edge sharpness.

Previous studies that measured heart rate to estimate energy expenditure used linear or logarithmic regression equations to relate oxygen uptake and heart rate (Richards & Lawrence, 1984; Renecker & Hudson, 1985; Purwanto et al., 1990). In this study, the draught force and the heart rates measured for the 1 to 8 mm cutting edges are best described with quadratic equations with R^2 of 0.98 and 0.99, respectively. The high R^2 is an indication that energy expenditure and stress of the animals correlates strongly with the depth of penetration, which varied for the 1 mm and the blunt 8 mm cutting edge with possible bulldozer effect.

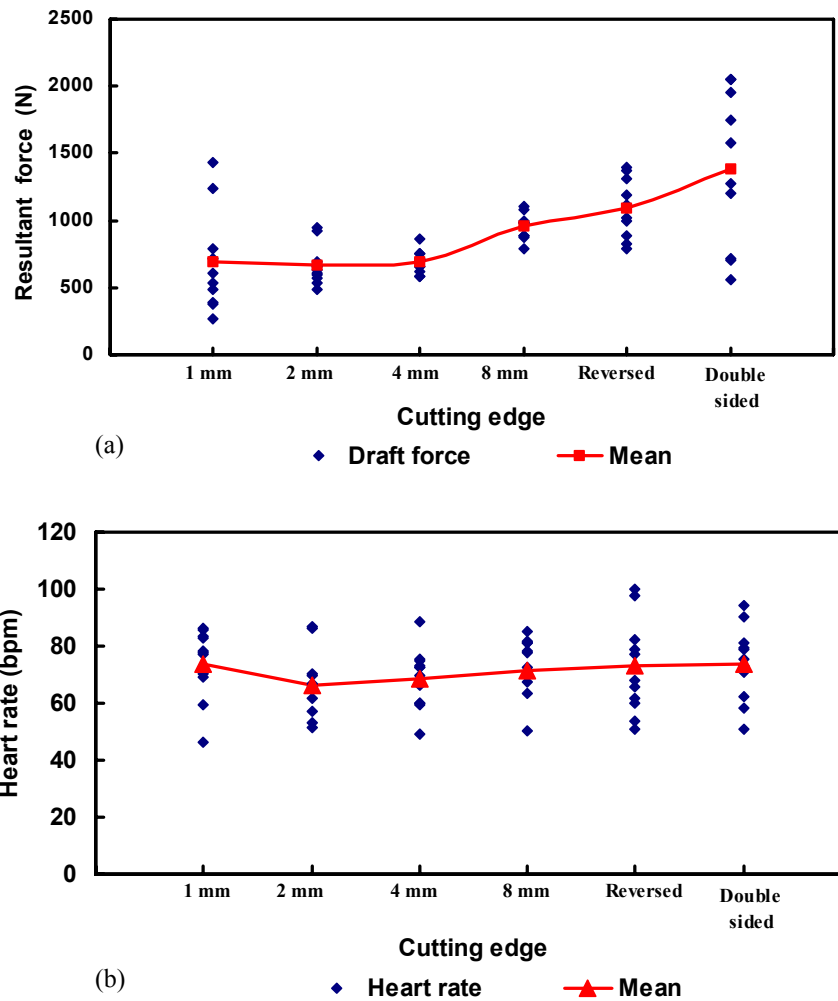


Fig. 12. Scatter plots of mean resultant draught forces (a) and heart rates (b) of the different cutting edges.

Cutting edge and durability

An important goal was to establish the relative cutting edge thickness spectrum at which draught force and the heart rates could be minimised. Considering the values of the depths of penetration, draught forces and heart rates for the 2 and 4 mm cutting edges, and from volume loss in the wear rate and durability considerations (Paper I), the 2-4 mm cutting edges are recommended for similar soils. However, this optimum cutting edge spectrum needs to be verified in unploughed soils.

Performance of worn shares

In Figure 13, clear differences emerged based on the state of wear when the draught forces and heart rates of worn shares were compared with new 2 mm cutting edge. Share wear and weight loss were highest for shares A and B and least for C and ‘arsws’. Contrary to popular belief that as tillage tools wear they become blunt and develop high draught forces, our study revealed that worn animal-drawn shares have thinner sections, lighter weights, sharper cutting edges, low penetration, low draught forces and low stresses on the animals.

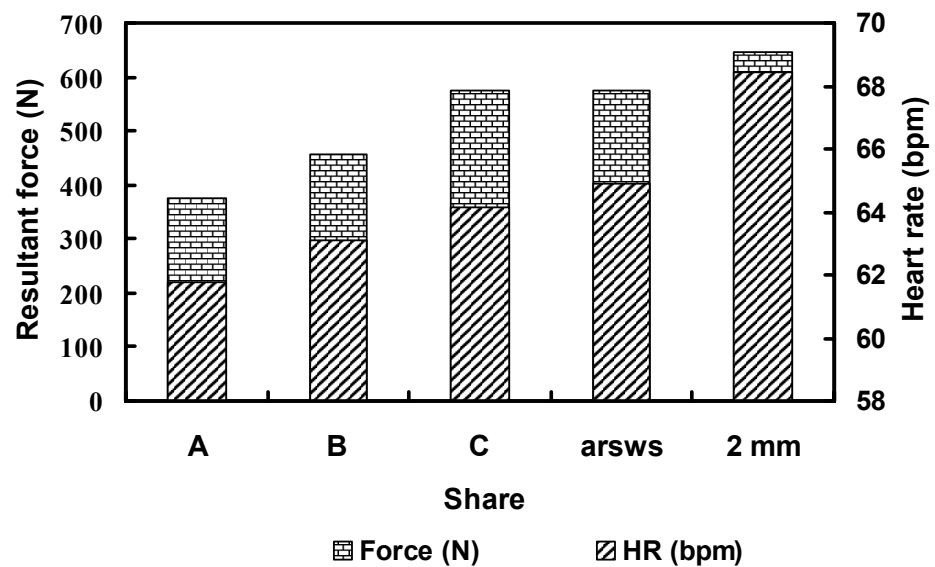


Fig. 13. Draught forces and heart rates of worn shares A, B, C and “arsws” compared with the 2 mm cutting edge.

Yoke effects on pulling force, speed and heart rate (Paper III)

The pulling force and average speed are inversely proportional for all the three yokes against the fixed loads (Figure 14). Pulling force increased linearly with increasing load ranging from 505 to 2209 N. Force values for the traditional yoke (SA) were higher than those of the ARS and the BBB at all load levels. Travel speeds decreased with increasing loads with high correlations of $R^2 = 0.99$, 0.98 and 0.97 for BBB, ARS and SA yokes, respectively. The increased force and the decreased average speeds signalled increased stress and decreased comfort levels the animals felt with the three yokes. At similar load levels, the animals moved faster with the improved yokes, suggesting less pain, enhanced comfort and welfare. Our results agree with the findings of Benson (2004), who emphasized that of all the states of suffering, pain is probably responsible in animal agriculture for a bigger reduction in welfare than any other. The high force values for the traditional yoke could be due to its elevated position on the neck of the animals

(Paper III). Until now, the traditional yoke has evolved over a trial-and-error process, with most of the designs with farmers remaining practically unchanged.

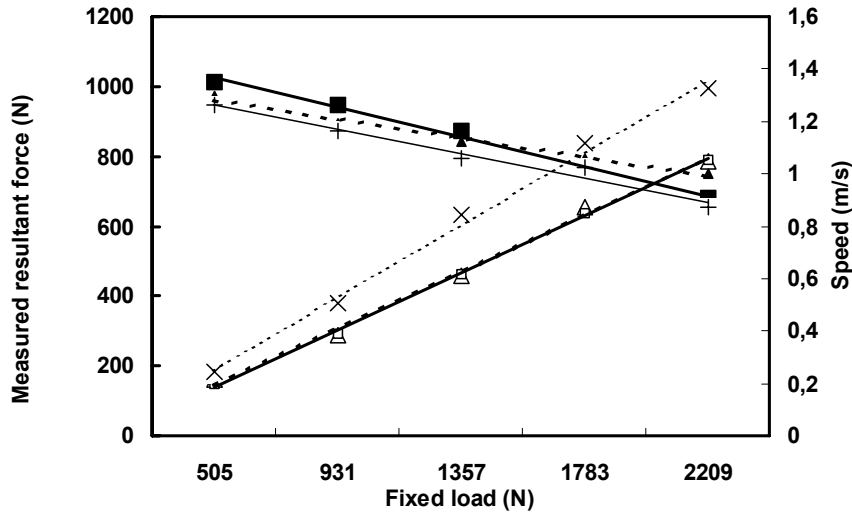


Fig. 14. Measured pulling forces and travel speeds versus fixed loads for the three yokes (ARS, BBB, SA) with constant chain length and angle of pull (13.08°); \triangle , ARS force; \square , BBB force; \times , SA force; \blacktriangle , ARS speed; \blacksquare , BBB speed; $+$, SA speed; $---$, Linear (ARS force); $---$, Linear (BBB force); $---$, Linear (SA force); $---$, Linear (ARS speed); $---$, Linear (BBB speed); $---$, Linear (SA speed).

Figure 15 displays a typical heart rate profile for an ox when pulling with ARS yoke. The occasional spikes at no-load stage could be stress conditions caused by fear or aversive stimuli experienced by the animal during confinement, restraint and instrumentation. These physiological and behavioural changes may be response to restraint conditions adopted before work, which results are in agreement with the conclusions of Mitchell et al. (2004), who analysed standard livestock handling and restraint techniques in cattle. In the absence of other painful stimuli, restraints alone can increase the heart rate and plasma cortisol concentrations of cattle to levels comparable to those recorded during transport and slaughter (Lay et al., 1992). The recorded working heart rate varied from a minimum of 36 bpm to a maximum of 117 bpm with a coefficient of variation of 30%. During the test period, after the external load was removed, the heart rate decreased rapidly towards the resting condition, indicating the animal recovered normally from the stressed conditions. The average heart rates of the animals were lowest when pulling with ARS and BBB yokes compared with the traditional yoke (SA) as shown in Table 2. Heart rate is an indication of the animal's physiological response to the loading situation. The heart rate measured and profiles were representative of the animal's response to the isolation, restriction, instrumentation and external loads experienced.

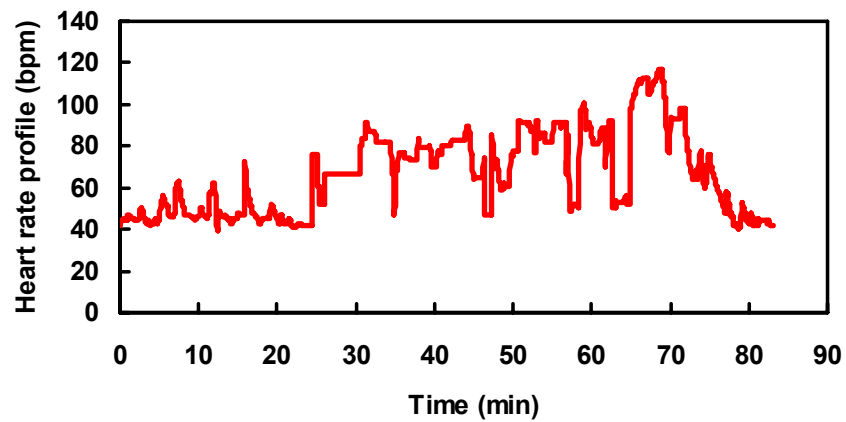


Fig. 15. Typical heart rate profile of SangaR during one pulling experiment with ARS yoke

The pairwise comparison in Table 2 shows the animals normally developed higher average heart rates with the heavier loads. As expected, SangaL, which was the lighter oxen and walked on the left, travelled more distance including headland turns, had higher average heart rates for all load levels and yokes than SangaR. This result agrees with the findings of O'Neil and Kemp (1989) and Aguirre and Orihuela (2000), who also got lower heart rates for the heavier oxen in similar experiments in India and Mexico. It is acknowledged during confinement, instrumentation, harnessing and work, the animals used had their flight zones penetrated and no possible escape route left for them to flee. This could be one possible explanation and a major source of anxiety that could alter their behaviour and affect their heart rates in agreement with Grandin (1993).

Table 2. Pairwise Comparison of mean heart rates (bpm)

F1 (Load, N)	SangaL	SangaR
2209	118.7a	105a
1783	107.5b	97.7b
1357	105 b	83.9c
931	105.6b	78.6c
505	78.2c	70.3d
F2 (Yoke)		
ARS	91.4b	83.4b
BBB	105.5a	91.3a
SA	112.1a	86.7ab

The hypothesis that there was no yoke effect on the heart rates (comfort levels) of the animals when pulling with the three yokes at the various load levels was not supported by the data. There existed significant differences ($p \leq 0.05$) in the comfort levels felt by the Sanga oxen pair when pulling various loads with the

three yokes. For both animals, using the heart rate as a proxy for the comfort levels of the yokes, ARS yoke was more comfortable in pulling than BBB and SA. The animals were used to the ARS and the SA yokes before the experiments. The result of high heart rates at high draught forces indicating the animals were stressed at higher loads, agree with the findings of O'Neill & Kemp (1989), who used heart rate to compare work output of oxen. Measurement of heart rate during work was used to assess comfort and welfare of DAs. The interaction of the behavioural and physiological factors in causing stress when pulling loads by Sanga oxen and the welfare characteristics of the yoke designs compared to the traditional yoke has been demonstrated.

Camel endurance and heart rate profile (Paper IV)

A typical plot of camel heart rate profile when pulling loads has four distinct stages (**A, B, C & D**) as shown in Figure 16. These are the initial resting condition (A), dynamic state, which was a rapid rise when loading begins (B), steady state, when increasing the load does not increase the average heart rate (C) and recovery or no-load state, when the load was removed (D), respectively. The combination of all the other states is termed 'global'. The heart rate at stage A was fairly uniform with occasional spikes and an average value of 49 bpm. The HR rose rapidly for about 4-5 min during the dynamic state when the camel started pulling load, before it attained a steady state at C. The short dynamic state illustrates the importance of taking measurements while the work was in progress. The steady state heart rate varied between 62-106 bpm, with a mean of 88 bpm. Once the pulling exercise stopped, the heart rate dropped rapidly from 93 bpm to the initial level of 50 bpm within 8-15 minutes. This implied that, provided the animals are loaded within certain limits, when the loads are removed, the animals will quickly recover.

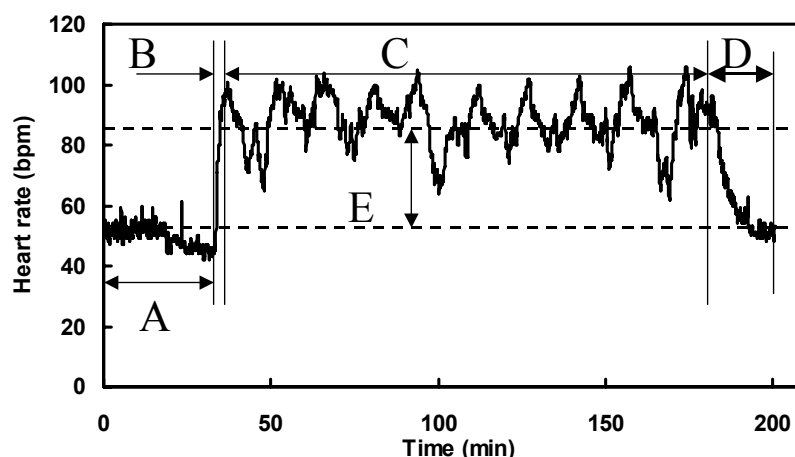


Fig. 16. Typical heart rate profile of Camel 817 pulling loaded sledge during the experiment. E is the average increase of the heart rate from the initial resting condition to the steady state condition

The pulling ability of draught animals is related to their live body masses, training levels and implements in use. More strenuous efforts are required to pull loads and implements with high frictional resistances making the animal to use greater energy from its muscle. Generally, loaded carts in the experiments produced lower rolling resistances due to the wheels, enabling the animals to carry more load, developed lower heart rate and walked faster over longer distances before showing altered behavioural signs. In this study, the maximum rolling resistance and coefficient of friction of loaded carts and sledges were determined to be 0.35 and 0.52, respectively. Heavier animals pulled relatively lower loads with respect to their body weights than lighter animals, making lighter animals more stressed.

Comfort and welfare (Papers II, III & IV)

Maintenance in teams of two and three in social groups, and other restrictions of behavioural opportunity were considered in the oxen and camels used during the study. The oxen always resisted instrumentation, harnessing and rushed out of the crush pen upon release. Cattle being prey species that strongly depend on their vision to assess their environment, the oxen occasionally attempted to rush and join other cattle that passed-by during confinement and work. These behavioural responses were responsible for the occasional rises in the heart rates. Unlike the Sanga oxen pair, which showed amicable behaviour and were tolerant of each other during work, and grazing after work, the camels separated and spent more time alone, avoiding social contacts after work. All the animals used in our experiments were observed to be less playful than their non-working compatriots, an indication of poor welfare in agreement with the findings of several researchers (Mellor et al., 2000; Hay et al., 2003), who concluded isolation is likely to be a behavioural adaptation with a protective role.

Qualitative observation methods employed to analyse the daily behaviour of the animals during the tests revealed common behaviour patterns. In the case of the oxen, these were refusal to enter confinement to be restrained for instrumentation, frequent urinating, defecating, aggressive head and horn swaying, head butting, feet stumping, tail swishing, loud vocalizations, and skin shaking whenever they were touched to apply water and transmission gel. Generally, these behavioural alterations some of which could be as painful as castration (Taylor et al., 2001; Hay et al., 2003), were adopted to minimise stimulation of affected tissues, due to a specific activity, instrument or external loads in agreement with the findings of Mellor et al. (2000); and Moya et al. (2007).

Results obtained from these studies highlight the value of behavioural observations for assessing work-induced pain and distress in draught animals. Blunt and worn ploughshares, traditional yoke, loaded sledges and carts caused specific pain related behaviours, and also altered the occurrence of behaviours normally displayed by the animals. These responses the animal displayed when restrained during work were used to assess pain and measure distress and were found to be in agreement with the findings of Flower & Weary (2006).

Camel behaviour and welfare

Animal behaviour and welfare were measured using speed as quantitative variable alongside qualitative variables such as refusal to walk, vocalization, urinating, defecating, sweating and lying down. The animals showed different behaviour tendencies during various stages of the test. For nearly the same loads with the same implements but on different days, the three camels covered different distances from 6.5-30 km, exhibited similar steady state heart rate profiles and behaviours at the end of each pulling exercises. During hot afternoons all animals refused to work. On the third day of working, camel 825 pulled a cart for only 30 minutes over 1.6 km distance and it developed the highest heart rate of 111 bpm, became fatigued, refused to walk, sat down, sweated, defecated and vocalized. The maximum load pulled was 562 kg, which was 143% of its bodyweight and 73% pull to live weight of this lightest camel.

Cluster analysis using single linkage Euclidean similarity method shows dendrogram for the steady state heart rates and time effect for the camels. Two main clusters are created at 74% similarity for the carts and sledges for all stages (see Figure 17).

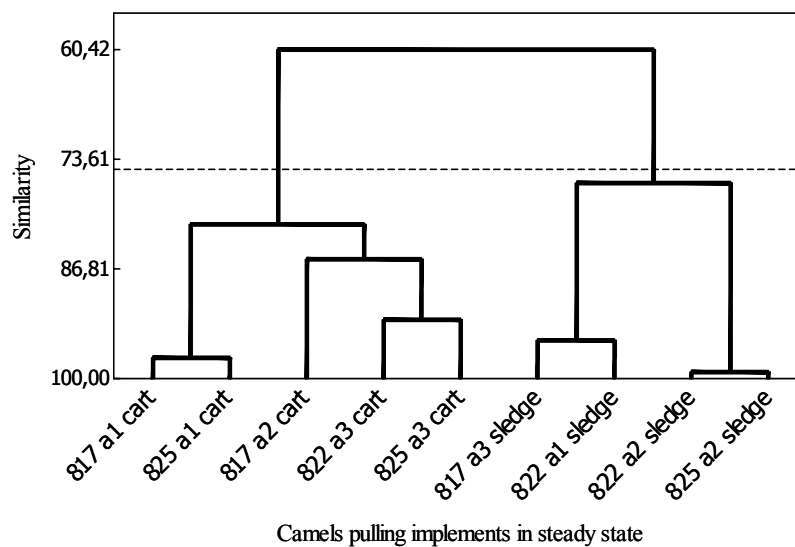


Fig. 17. Dendrogram of mean heart rate with respect to time for the three camels at the steady state as the animals pulled loaded carts and sledges. a1, a2 and a3, represent the three consecutive days of the experiment.

Within the cart cluster, for all three states, the closest physiological similarities occurred between camel 817 and 825 when pulling on the first day. The next closest similarity occurred between camels 822 and 825 when pulling cart on the third day. Cart pulling by camel 817 on the second day appeared to be an outlier

for all states. Within the sledge cluster, the heart rate of camels 822 and 825 on the second day have the closest similarity, with the highest similarity occurring during the steady state for the two camels.

General discussion

A necessary condition for the adoption of draught animal technology or any other technology is that it should be profitable and lower the total cost of production of goods and services. With regards to draught animals (DAs), which are sentient beings that experience pain and pleasure like human beings, and require humane treatment, animal welfare issues play important roles in their productivity. In this thesis, data from field experiments in Ghana and Kenya are used to demonstrate how the absence of certain pre-conditions and the presence of other constraints can inhibit the utilization of animal traction in parts of sub-Saharan Africa.

Important factors that improve the performance and productivity of draught animal technology include among others; ploughshare durability, optimum cutting edge sharpness, appropriate yoke designs and implement type (loaded cart or sledge) and their effects on welfare. Abrasive wear and its effects on the share to effectively cut and lift the soil slice, the replacement of a worn share, the time lost in changing and costs are significant if done frequently. Thus, it is desirable to increase the share life through the development of more durable and wear resistant shares to reduce production cost to farmers. This will make the adoption of the technology sustainable and address the concerns of farmers similar to the situation reported in Niger, where animal traction farmers abandoned the technology due to cost of replacement parts (Williams, 1997). One possible explanation is that imported machinery and parts are expensive because they require scarce foreign exchange.

Results of laboratory tests used to investigate share chemistry, hardness and production process of ploughshares identified three share production processes as industrial press forging, blacksmith forging and foundry casting. From the metallurgical and statistical analyses, it was evident that the properties of shares differ significantly based on producers and the production methods. This study realised that it is not satisfactory to allow our farmers to depend on expensive but durable imported or the fast wearing blacksmith shares only. The blacksmith-forged shares, which were ductile, soft and low in abrasion resistance, could be improved with heat treatment. Unfortunately, the scrap metal raw material source for the blacksmith share production especially in Ghana is threatened, as it also constitutes the main raw material base for the existing industrial steel mills. However, cast iron shares also tend to be hard but brittle and fracture in use with reduced life.

For example, due to lack of press forging facilities during the study period, and the widespread artisan casting skills available, cast steel shares, which combine both hardness and ductility properties after heat treatment were produced. Under

the farmers' own conditions and with minimum supervision, the new cast steel share was tried and tested by farmers, who served as jury, returned a positive verdict on the share's ability to withstand shocks, fracture and rapid wear. Comparative wear study of the imported, blacksmith and cast steel shares was done in farmers' field to investigate wear rates of shares from different producers to rank share durability and for determining replacement schedule. Some of the wear data and field comparative results are reported in **Papers I and II**. A significant reduction in wear rate occurred with the new cast steel share compared with the imported and blacksmith versions. The field test results showed the cast steel share durability exceeded 5 ha/share comparable to the imported share. Clearly, this cast steel technique has promise for mass production. The new chemical formula could be adopted for other soil engaging implements like planters, weeding cultivators, ridger shares, and harvesters.

The relations between share wear rates and share chemical composition, hardness and soil physical factors and texture were also demonstrated (**Paper I**). Naturally, higher sand content of soils was found to be strongly correlated with share wear in agreement with results from literature. It is acknowledged the study did not demonstrate effectively the role of soil moisture on wear rate, because moisture content could not be regularly and accurately monitored on the farmers' field. However, the field results made it clear the principles behind the development of these shares were justified. The results also confirmed the findings of Owsiak (1997), that the wear of soil cutting tools is influenced by chemical composition of the steel and its heat treatment, the soil type and conditions, operational factors and characteristics of the tool, the distance travelled or area worked, and for multi-tine arrangements, the position of the wearing part of the tool. Some of these principles are suggested in the '*performance index*' concept proposed in this thesis.

In our study, we adopted the principle of participatory technology development approach, whereby the major stakeholders (farmers, ploughboys, blacksmiths, foundries and agricultural extension officers) were involved in the development and trial stages. This gave major stakeholders the opportunity to provide deeper insights into their experiences with various shares and their expectations for the new project. This approach is aimed at long-term sustainability of successful study outcomes.

The promising results from the newly developed cast steel share were extended further to determine optimum cutting edge thickness that generates the best animal welfare indicators such as high pulling speeds and low heart rates. The prior ploughing and harrowing of the test field in this study reduced the effects of soil heterogeneity and made the influence of cutting edge thickness to reflect on depth of penetration, pulling force, speed and heart rate of the animals to be evaluated. The higher draught force and heart rates values obtained for the 1 and 8 mm cutting edges compared to the 2-4 mm edges showed that the optimum share sharpness from welfare point of view lies within 2-4 mm spectrum. Comparing the effects of the location of the 2 mm cutting edges on the depth of penetration, draught force and heart rates for the conventional, the reversed and the double

sided cutting edges, the lowest results were obtained for the conventional, confirming its cutting edge geometry was the best under the experimental conditions.

In this study, the relative significance of the yoke design on the comfort and welfare of the oxen was also evaluated. The anticipation of pressure points on the animals and methods of reducing them were the basis of the yoke design and testing experiments. It was found that yoke designs with shaping to fit the neck region had significant effects on heart rate and speed values with implications for improved comfort and welfare. Among the three yokes tested, the BBB had the largest contact areas on the animals' necks and was the heaviest, but the heart rates and force values it generated were intermediate between the lighter improved ARS and the traditional SA yokes. It is likely if all the yokes were of the same weight, there might be marked improvements in the results obtained with the BBB yoke. High heart rates, increased resistance pull for the same fixed loads and low speed of the traditional yoke are indications that the loading and yoking device increases the stress response above that associated with improved yokes (ARS and BBB) with better fitting area on the neck region. In operation, the traditional yoke is observed to roll up the withers towards the hump, thus increasing the hitching angle with corresponding increase in the vertical component of the load. These conditions suggest therefore that the traditional yoke, when fitted was painful, aversive, or physically restrictive for the oxen and appeared to have obvious welfare implications under the studied management condition. The fact that general activity and the alertness of the animals in the form of high heart rates and behavioural alterations increased at work suggest that these were escape or avoidance behaviour in response to work and other restrictions. The absence of any detectable skin or muscular damage in the yoking experiment is not surprising because of the short duration of each experiment and the test period. In longer trials and especially under farmers conditions, one could expect that at least few of the treatment animals would have shown some chafing, harness sores or similar, from the harness or whip wounds.

The Duncan's mass comparison test revealed associations of yoke design parameters with heart rate and behavioural patterns ([Paper III](#)). The fast recovery of the heart rates and amicable behaviour observed after the working regimen in the study suggest work heart rate increases were not at levels that might risk the animals' health. This confirms that oxen, just like horses show characteristic behavioural patterns when subjected to mental and physical stresses during work. The decrease of the stress indicating behaviours was clear during no-load periods for both the camels and the oxen. Whether the reduction was mainly due to less external load during grazing and resting or whether the reduction was due to increased willingness to calmly co-operate during work or testing sessions between the two sets of animals, remains subject to speculation. The current study demonstrated clear effect of confinement, instrumentation and work on low speed, increasing heart rate, vocalizations and defecations in agreement with the findings of Mitchell et al. (2004). It has been previously established that the propensity for cattle to vocalize is influenced by phenotype (Watts & Stookey, 2001) and by painful procedures (Watts & Stookey, 1999). These behavioural adaptations can

be described as protective, allowing animals to avoid or reduce the stimulation of painful tissues (Mellor, Cook & Stafford, 2000). Several researchers have discussed the importance of vocalization, defecation and other behaviour alterations as methods for welfare assessment. It is believed more studies need to be done in a broad spectrum of species-specific distress vocalizations and defecations for example in other cattle species like Ndama, Zebu or the WestAfrican shorthorn, to reach a firm conclusion.

Draught animals undergo suffering in many ways, such as overloading, beating and whipping, harness sores, lack of adequate feed and rest, all culminating in excessive strain and stress. They become very weak, overworked and overstressed especially at the start of the working season. Sometimes sick and injured animals are made to work otherwise, the owners who eke out subsistence living would starve. In several instances, poor farmers who cannot afford better equipment are also insensitive to animal suffering and welfare culture (Ramswamy, 1998).

The field results have confirmed evidence in literature that equipment attached to DAs, such as ploughs, carts and yokes and other harnessing devices that are of crude design, and inefficient hurt animals. Harnessing and yoking may be stressful from welfare point of view, but it is not likely many farmers pay much attention. Welfare programmes should prevent cruelty, pain and foster care and well-being of animals. Justification for welfare is evident from the contributions of the DAs to agricultural production, small-scale transportation and bio-energy from their dung.

It could be postulated that training methods based on actual knowledge of species-specific communication will provide better control and safety rather than uncertainty and fearfulness in the animals. The increased animal-human confidence gained during training could lead to better performance and reduced distress, thereby increasing welfare.

In the evaluation performance of draught animals in this study, both the absolute weight of the external load and the resultant pulling force were used. Hitherto, many scientists evaluate performance in relation to external load only and weight of animals. However, it should be the actual load acting on the animal and in the form of the resultant pulling force that should be considered for the evaluation. Additionally, earlier studies show low load/live weight ratios because they never loaded animals to the maximum. It is clear the load acting on the animal through the pulling force is less than the absolute or actual load in the cart or sledge the animal pulls.

The resultant pull comprises both the vertical and horizontal components. However, the pull/live weight ratio may not be enough to describe the performance, therefore the concept of '*performance index*' is being introduced. The term '*performance index*' with such factors as animal weight, external load, welfare, speed, type of operation, duration, implement, surface condition, climatic condition included, is recommended.

Main conclusions

The study confirmed that to increase the productivity of the draught animal implement combination, it is important to consider the animal welfare aspect when optimising the design of implement and harnessing systems.

In this thesis, the performance of the draught animal-implement system was studied. As loads increased over test distances and days, animal behaviour altered through reduced speed, refusal to walk after short distances, sweating, urinating, increased vocalisation and defecation in all cases with welfare implications. Speed is a very significant factor ($p \leq 0.01$), which correlates strongly with heart rates of camels at work.

Chemical composition, share production method and hardness, soil physical factors and sand content are factors that affect wear rate. A chemical formula was recommended. Based on this formula, a cast steel ploughshare was manufactured. The results of the study showed that the newly developed share is equally durable as the imported version. Wear rate and durability of the cast steel shares was 3-8 ha per share compared with 1-2 ha for the locally fabricated blacksmith shares.

The wear rate of the new cast steel shares in three soil classifications were lowest in Eutric Plinthosols (146 g/ha) followed by Plinthic Lixisols (164 g/ha) and the highest values experienced in Haplic Lixisol (176 g/ha). The overall average wear rate of shares in the study fields was 162 g/ha, giving an overall durability, which was equally high as the imported shares.

The results of ploughshare cutting edge thickness on draught force and heart rates of Sanga oxen in Ghana confirmed that draught forces and heart rates of the animals increased with increasing cutting edge thickness from 1 mm to 8 mm with quadratic equation. From the draught force and welfare point of view the 2-4 mm cutting edge thickness is recommended.

The performance of different yoke designs in relation to comfort and welfare were assessed. The study confirmed that yoke design parameters have significant effects ($p \leq 0.05$) on physiological and behavioural responses of animals. Yokes with increased contact surfaces on the neck, improved comfort and welfare more than those with reduced contact areas in the neck region.

Travel speed change is inversely proportional to increased load and linearly related. Animals when confined for instrumentation and yoking, showed the most stressful behaviours such as urinating, defecating, vocalization, tail swishing, stumping and other aversive behaviours, which compromised their comfort and welfare.

In this thesis, two ways of load and live weight were used to study the performance of animals: (a) absolute load and live weight ratio (b) pulling force and live weight ratio. The maximum loads pulled during the field experiment by

camels were 5620 N and 2490 N with carts and sledges, respectively. The load/live weight ratios for the three camels ranged from 119-143% with cart, and 53-64% with sledge, respectively

The pull/live weight ratios for the three camels ranged from 29-51% and 15-30% for cart and sledge, respectively. At travel speeds of 1-1.8 m/s, the animals generated steady state heart rates from 78-111 bpm for cart and 88-113 bpm for sledges, which was an increase of 44-178% and 73-111%, respectively over the initial resting heart rates for all the three camels.

Recommendations and future work

This study has raised several issues, which will require further future research, some of which are presented below.

The cast steel shares have been proven in the end-user environment to satisfy demand. For this study to benefit farmers and the nation, a commercial production facility need to be established to produce these shares. Continued quality control measures are envisaged to ensure that farmers and other end-users get value for money from the shares. Mass production could also be done in agreement with existing steel mills in the country.

In this study, the wear rate of the new cast steel shares have been investigated in only three main soil series in Ghana. Long-term field-testing regarding wear rate in other major soil series in the country is encouraged to determine wear rate in different soils. This should inform future soil-specific quality improvements of shares produced.

Further testing are required into soil physical parameter effects on wear rate, e.g., varying sand, gravel or moisture content on wear rate in field and laboratory conditions. Nano-tribology and abrasive wear of ploughshares and similar soil engaging implements produced from the formula of the new cast steel shares should be investigated.

If usage is widespread, investigate further the ideal cutting edge spectrum in the regular and reverse cutting edges of shares in most animal traction soils in the country. Further research seems justified to specify the ideal cutting edge of tillage implements and the effect on tillage performance in different/major soils.

Determination of optimum pulling capacity of existing oxen and donkey breeds should be pursued. Use of different yoke designs on other breeds of oxen with increased sample sizes is envisaged.

Most of the raw material base for the blacksmiths and the foundries are scrap metals of imported machinery. The existing steel mills in the country also use these scraps to produce mainly architectural steels. There is the need for research

into the policy and economic implications if the steel mills are to produce engineering steels to support the small and medium-scale enterprise (SME) manufacturing industries and the blacksmiths in the country.

The donkey (*Equus asinus africanus*) for traction and transport is one important draught animal that is gaining popularity among women and farmers in border villages and along main highways where cattle theft is common. The donkey was not considered in this study because it was not so popular as oxen and camel and also due to time constraints. The donkey traction was unpopular partly due to the initial exposure of farmers to only cattle traction, and partly because of the good resale value of work oxen, which serves as an important savings mechanism for farmers compared with that of donkeys. However, available evidence in semi-arid West Africa indicates that the investment required for donkey traction is only about 30-40% of that needed for bovine traction, while the benefit streams of the two traction techniques, especially for weeding, are comparable (Jaeger and Matlon, 1990). This suggests that promotion of donkey traction together with changes in cropping patterns might benefit farmers, particularly in areas, where the potential exists for profitable use of animal traction. It is hoped most of the methodologies employed in this study are relevant and applicable to the donkey in future studies to enable the women's group and other vulnerable communities not having access to oxen to benefit from the improved technology and welfare issues investigated.

The biochemistry and measurements of basal salivary and plasma cortisol in future study on working animals should provide any evidence of activation of the hypothalamic–pituitary–adrenal axis. The ACTH challenge test should be taken after the oxen had been working with harnessing device to provide evidence of stress. Activation of the HPA axis can lead to an increased sensitivity of the adrenal cortex to ACTH (Terlouw et al., 1998). Visual and statistical analyses of observation results of gait and spinal restrictions, manual examination of the skin, muscles and regional vertebral motion of draught animals should reveal any effects of the harness and the pulling implement/device used.

In the present thesis, the concept of ‘*performance index*’ has been introduced to obtain a comprehensive evaluation where not only the external load, but also, welfare, speed, type of operation, duration, implement, surface condition, climatic condition are included. This concept needs to be verified with more field data.

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